Particle Physics

Phys 198

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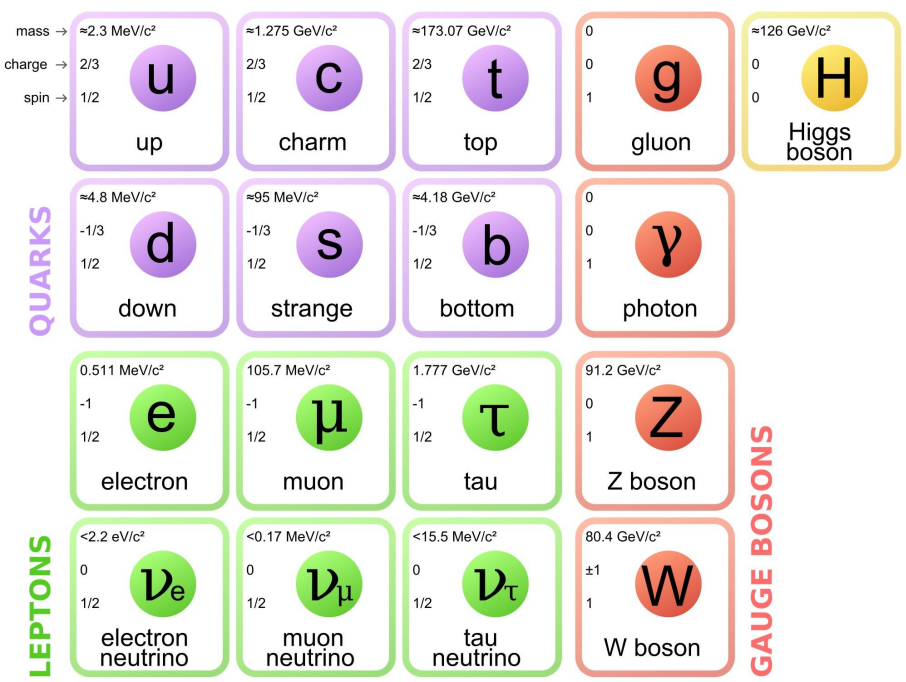
Basics of Standard Model



General Terms

Spin

- Fermions - half-integral spin (½ ħ, 3/2ħ, ..) such as electrons, protons, neutrons
- Bosons - integral spin (ħ, 2ħ, ...) such as photons

Quarks and Leptons

- Main difference is that quarks interact through strong nuclear force, while Leptons don't

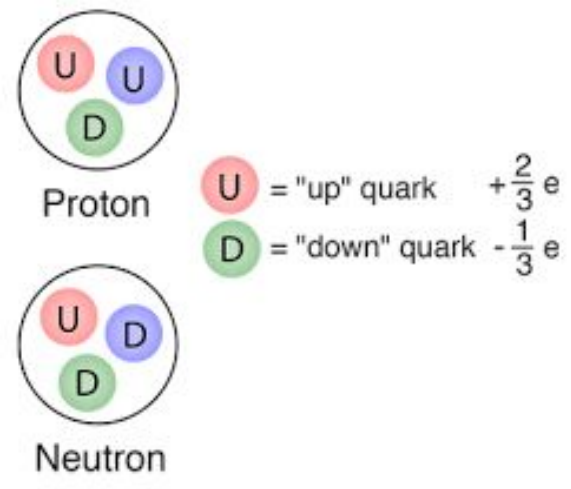
Hadron

- group of two or three quarks
- Two quarks is a meson and group of three quarks is a baryon

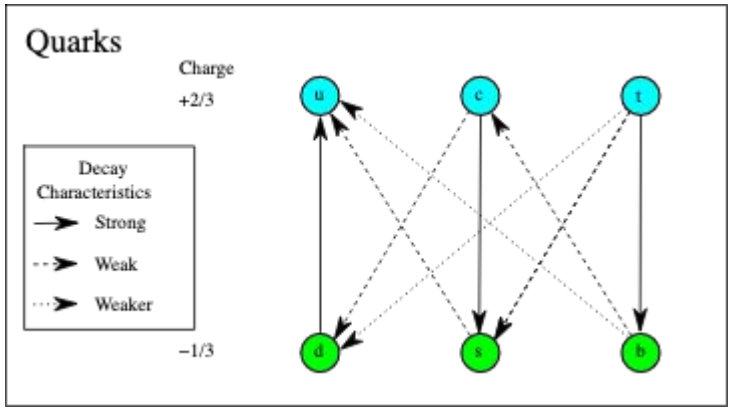
Particles have a corresponding antiparticle (same mass but opposite charge)

- positron (antielectron), antimuon, etc.
- Neutral particles are their own antiparticles (photons)

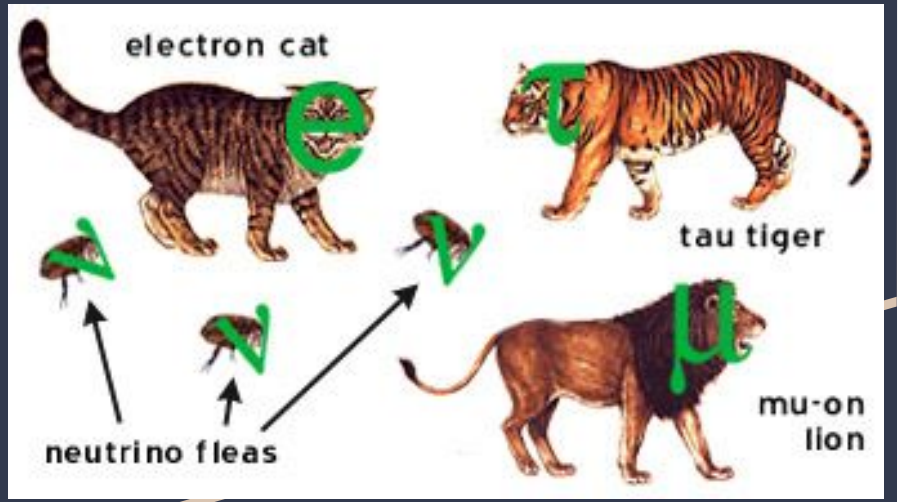
About Quarks



- 6 types: Up, down, charm, strange, bottom, top
- Only make up hadrons
  - Baryons: protons, neutrons
  - Mesons:
- Heavier quarks (charm, strange, bottom, top) decay into low mass quarks (up, down), so most quarks in universe are up and down quarks
- See charm, strange, bottom, top in high energy particle accelerator experiments.
- All quarks have antiquarks in their flavor
- Spin of +/- ½



About Leptons

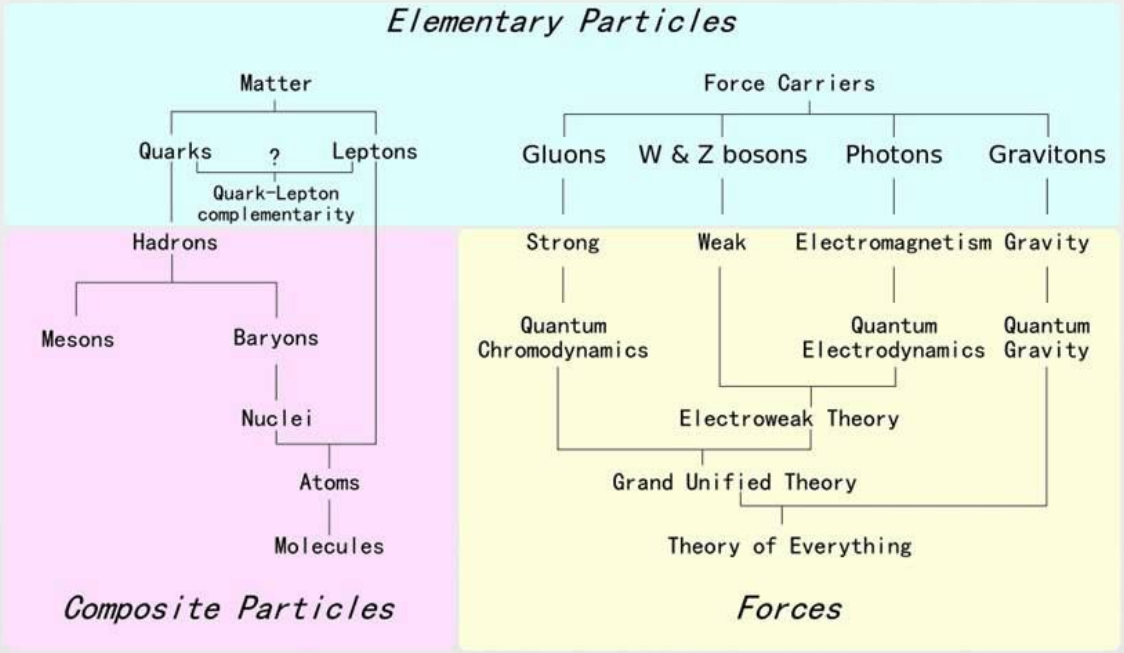


- Charged leptons: electron, muon, tauon
- neutral leptons: electron, muon, and tau flavored neutrinos
- Through particle decay, high mass leptons decay to low mass (electrons have lowest mass) (also neutrinos have mass)
- Muons and taus seen in high energy collisions
- Do not experience strong interaction
- Leptons have antileptons, still seeing if neutrino is its own antiparticle
- Spin of +/- ½

Four Fundamental Interactions

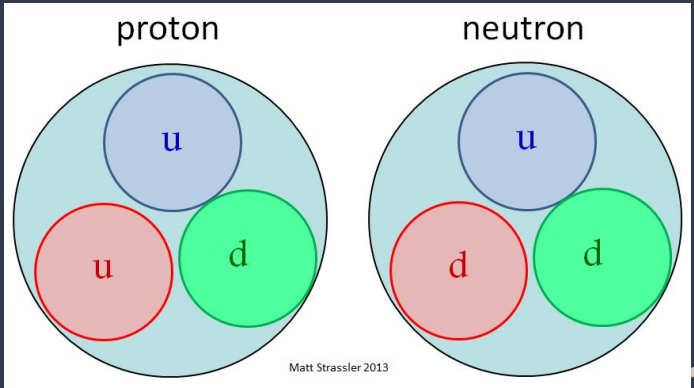
Interaction	Current theory	Mediators	Relative strength[20]	Long-distance behavior
Weak	Electroweak theory (EWT)	W and Z bosons	10^{25}	$\frac{1}{r}\, e^{-m_{\mathrm{W,Z}}\, r}$
Strong	Quantum chromodynamics (QCD)	gluons	10^{38}	$\sim r$ (Color confinement, see discussion below)
Electromagnetic	Quantum electrodynamics (QED)	photons	10^{36}	$\frac{1}{r}$
Gravitation	General relativity (GR)	gravitons (hypothetical)	1	$\frac{1}{r}$

Bound state



https://en.wikipedia.org/wiki/File:Particle_overview.svg

Bound States



Nucleons

- Quarks can't exist in nature alone, so they clump together through the strong force
- Protons are made of two up quarks and one down quark (2*⅔ - ⅓ = 1)
- Neutrons are made of two down quarks and one up quark (⅔ - 2*⅓ = 0)

Other

- In general two combinations
  - Mosons: Quark and Antiquark
  - Baryons: 3 Quarks

Decay

Decay Type	Radiation Emitted	Generic Equation
Alpha decay	${}^{4}_{2}\alpha$	${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}X' + {}^{4}_{2}\alpha$
Beta decay	${}^{0}_{-1}\beta$	${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}X' + {}^{0}_{-1}\beta$
Gamma emission	${}^{0}_{0}\gamma$	${}^{A}_{Z}X^{*} \xrightarrow{\text{Relaxation}} {}^{A}_{Z}X' + {}^{0}_{0}\gamma$

Decay equations are written with the parent nucleus on the left hand side, and the daughter nucleus on the right hand side (with change in atomic number and atomic mass) and the emitted particle

Alpha

- occurs in heavy unstable nuclei
- emission of 2 protons and 2 neutrons (Helium 4-nucleus)

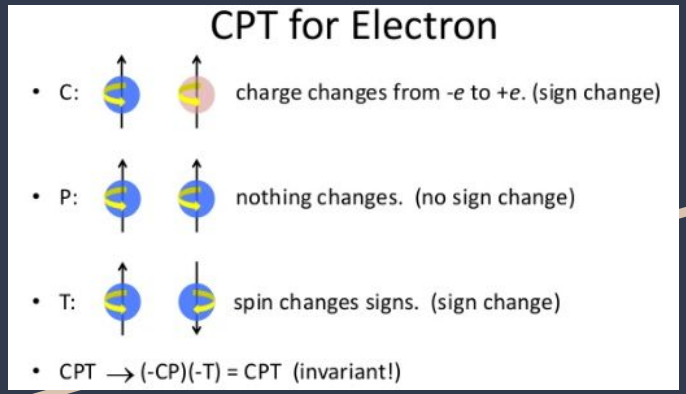
Beta

- occurs through weak nuclear force
- Beta-Minus
  - Neutron converts into a proton, a neutrino, and an electron, where the electron is emitted
- Beta-Plus
  - Proton converts into a neutron, a neutrino, and a positron, where the positron is emitted

Gamma

- particle in excited state goes to a lower-level state through emission of photons

Symmetries And Conservation Laws



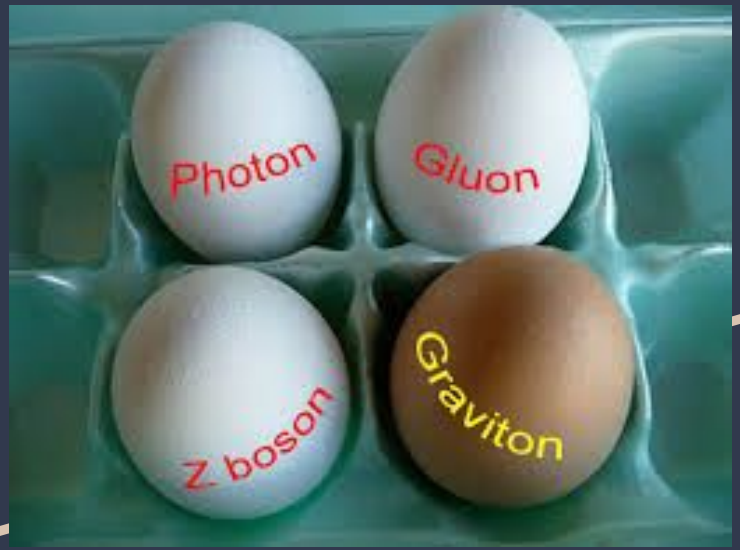
Conservation Laws

- Arise from conservation of Lagrangian
  - Noether's Theorem
- QFT shows that charge, baryon number, and lepton number add an imaginary exponential
  - Invariant across space -> global conservation
- Explains why some decays don't happen
  - Proton to Position should happen with conservation of charge, but conservation of baryon number prohibits it

Symmetries

- Three fundamental symmetries
  - Charge
  - Parity (mirrored)
  - Time

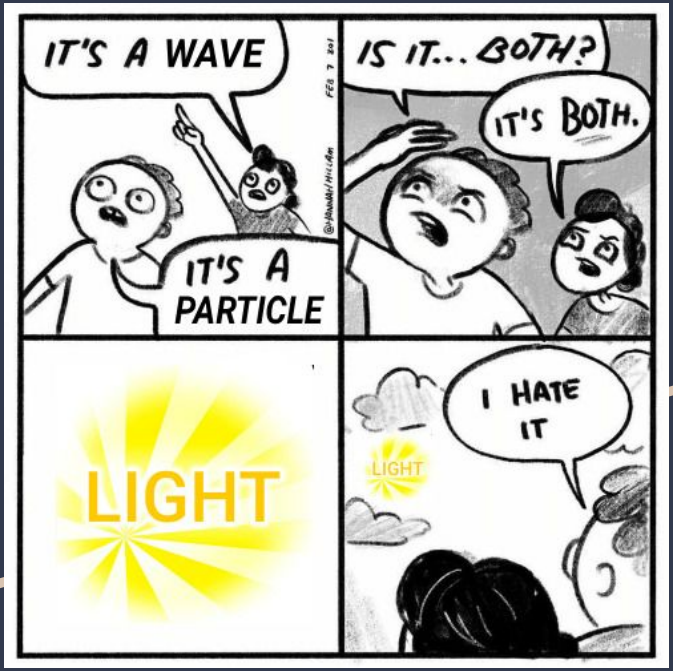
Practice Problems



1) Which combination of quarks is a valid baryon?
   a) u
   b) sd
   c) uudd
   d) ddd
   e) c

2) Which boson “gives” mass?
   a) Gluon
   b) Photon
   c) W Boson
   d) Z Boson
   e) Higgs

Practice Problems



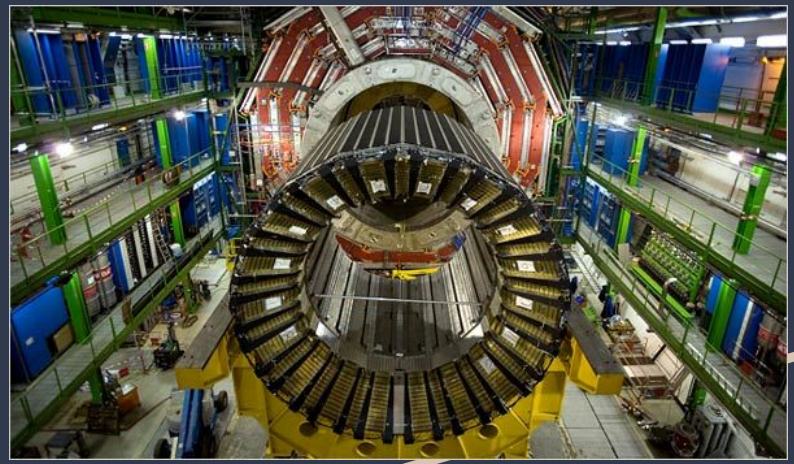
3) The particles carrying the strong force are the:

   a) photons
   b) gluons
   c) Z- or W- bosons
   d) neutrinos
   e) muons

4) The existence of neutrinos was postulated to explain:

   a) Alpha decay
   b) Gamma emission
   c) Beta Decay
   d) Fission
   e) Fusion

Practice Problems



5) What is the usual lifetime of particles that decay electromagnetically?

a) 10^{-23} seconds
b) 10^{-18} - 10^{-16} seconds
c) 10^{-10} -10^{-8} seconds
d) Impossible to tell without more details of the particles
e) None of the above

6) Which of the following is a possible solution to the below reaction?

$\bar{p}$ is an antiproton.

$$\bar{p} + \bar{p} + p + p \rightarrow (\qquad)$$

a) $\bar{p} + \bar{p}$
b) $p + p$
c) $\bar{p} + p$
d) None of the above
e) More than one